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ESTIMATING FUEL WEIGHTS OF GRASSES, FORBS, AND SMALL WOODY PLANTS

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ABSTRACT

Equations were developed for estimating fuel loading (g/m²) of grasses, narrow-leaved forbs, broad-leaved forbs, and small woody plants common to western Montana and north Idaho. Independent variables were plant height and percentage of ground covered. R^2 *for the equations ranged from 0.30 to 0.91. The equations provide reasonable estimates for vegetation similar to that sampled in this study; however, accuracy could decrease significantly if the equations are applied to dissimilar vegetation. Differences in ocular estimates of ground cover between observers averaged 5.8 percentage points.*

OXFORD: 431.2, 431.5
KEYWORDS: forest fuel, sampling methods, grass-forb biomass

Some methods for appraising potential fire behavior of fuels (Albini 1976) require estimates of loading (weight per unit area). Loadings of grass and forbs are particularly important for predicting fire behavior, especially rate of spread, because these fuels are finely divided and burn rapidly when dry. To aid in appraising fuels, a quick, easy-to-use method is needed for estimating loading. Techniques commonly used to estimate loading of grass and forbs require some clipping, drying, and weighing. The study reported here attempted to eliminate the need for clipping, drying, and weighing by relating loading of grass and forbs to the easily obtained variables--plant height and percentage of ground covered. The consistency of ocularly estimating ground cover was also determined.

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Previous studies gave reasonably high correlations between loading and ground cover and height; thus, we were encouraged to determine correlations for mixtures of grass and forb fuels. The simple linear correlation coefficient for the relationships between yield, and the product of ground cover and height, was 0.91 for pasture grasses (Pasto and others 1957) and annual range species (Reppert and others 1962). In both studies, correlations involving the product of ground cover and height were higher than those involving only ground cover. For several annual grasses and broad-leaved plants, Evans and Jones (1958) found simple linear correlation coefficients of 0.86 and 0.99 for the relationship between loading and the product of ground cover and height.

METHODS

FIELDWORK

Loading, height, and ground cover for mixed species of grass, forbs, and small woody plants were measured on plots 30 × 60 cm from 14 forest stands in western Montana and north Idaho. To provide a variety of understory species in the samples, stands were selected on sites that ranged from dry to moist, and in ages from newly established to mature. In each stand, 10 plots were systematically located 1 chain apart. Data were recorded for each plot unless several plots having similar species composition and ground cover had already been taken.

Each plot was categorized into grass, broad-leaved forb, narrow-leaved forb, and small woody vegetative groups (table 1). Species that dominated the ground coverage determined the vegetative groups. Species were grouped anticipating that accuracy and precision would be improved by determining weight relationships for species having similar sizes and shapes.

Plots were delineated with a 30 × 60 cm aluminum frame. The size was chosen because it was small enough to permit careful viewing for ocular estimates of ground cover and to permit clipping and weighing with reasonable effort, and it was large enough to include most plants in their entirety. At each plot, ground cover, defined as the vertical projection of plant area, was ocularly estimated to the nearest 5 percent. All grass, forb, and small woody species were included in a single estimate of ground cover for each plot. Ground cover was also determined using the line interception method (Canfield 1941). A sufficient number of line transects running lengthwise over the plots were used to estimate ground cover with a standard error within 5 percent of the mean. Height was measured to the nearest 5 cm as the distance from the forest floor to an apparent average top (plant height integrated ocularly over the plot area). All living and dead grass, forb, and small woody plant material above the forest floor within a vertical projection of the plot was clipped and ovendried at 95° C.

To determine consistency of observers in estimating ground cover, two observers independently estimated ground cover at each plot. In all, eight different observers having about one-half hour of training participated.

ANALYSIS

For each vegetative group, loading was estimated by a linear function of ground cover and height. Groups were tested to see if some of them could be combined without significant loss of ability to predict. Using linear regression analysis, log transformations were evaluated for both the dependent variable (loading) and several expressions of the independent variables (ground cover and height). The log transformations were discarded in favor of using loading in its original units as the dependent variable. Loading was then regressed on logical sets (models) of the following independent variables: ground cover, height, height squared, and the interactions of ground cover with height and height squared.

Table 1.--*Species groups and species dominating ground cover*[1]

Species group		Dominant species	
Grass	1.	Pinegrass	*Calamagrostis rubescens*
	2.	Elk sedge	*Carex geyeri*
	3.	Beargrass	*Xerophyllum tenax*
	4.	Pinegrass or elk sedge	
Broad-leaved forb	5.	Arnica	*Arnica* spp.
	6.	Bedstraw	*Galium* spp.
	7.	Pussytoes	*Antennaria* spp.
	8.	Strawberry	*Fragaria* spp.
	9.	Twisted stalk	*Streptopus amplexifolius*
	10.	Meadow rue	*Thalictrum* spp.
	11.	Western gold thread	*Coptis occidentalis*
	12.	Wintergreen	*Pyrola* spp.
	13.	Anemone	*Anemone* spp.
	14.	Queencup beadlily	*Clintonia uniflora*
	15.	Lady fern	*Athyrium distentifolium*
	16.	Violet	*Viola* spp.
Narrow-leaved forb	17.	Fireweed	*Epilobium angustifolium*
	18.	Goldenrod	*Solidago* spp.
	19.	Canada thistle	*Cirsium arvense*
	20.	Yarrow	*Achillea millefolium*
	21.	Flannel mullein	*Verbascum thapsus*
	22.	Fairy bell	*Disporum hookeri*
	23.	Bracken fern	*Pteridium aquilinum*
Small woody plants	24.	Kinnikinnick	*Arctostaphylos uva-ursi*
	25.	Twinflower	*Linnaea borealis*

[1] Species of minor occurrence are omitted from the listing.

RESULTS AND DISCUSSION

The prediction equations in table 2, and figures 1 and 2, all exhibited F ratios significant at the 99 percent level. For the range of data on which the equations are based, the predictions are reasonable. However, our data suggest that incorporating several species, even though of similar growth form, into a single prediction equation results in less accuracy than equations developed for single species. The equation for small woody plants had the best accuracy, probably because it was developed almost entirely from one species--kinnikinnick. This equation should be suitable for estimating loading of kinnikinnick for many purposes.

The equation for grass had the poorest accuracy, perhaps partly because ground cover is difficult to ocularly estimate. Narrow-leaved blades and stalks oriented primarily in an upright position create a fuzzy impression of how much ground surface is covered by a vertical projection of plant area.

Table 2.--*Equations for estimating loading (Y), g/m², from ground cover (X_1), and height (X_2), cm*

Species group	Equations	R^2	CV[1]
			Percent
Grass	$Y = 6.102 + 2.83 (X_1) + 2.432 (X_2)$	0.30	67
Narrow-leaved forbs	$Y = 192.4 + 0.05680 (X_2X_1) + 0.000914 (X_2^2X_1) - 0.05242 (X_2^2)$	.77	55
Broad-leaved forbs	$Y = -13.80 + 1.388 (X_1) -0.03040 (X_1X_2) + 1.156 (X_2)$	.68	41
All forbs combined	$Y = -28.14 + 0.001535 (X_2^2X_1) + 8.926 (X_2) - 0.1256 (X_2^2)$	.80	67
Small woody	$Y = 109.0 - 2.161 (X_1) + 0.1078 (X_1^2)$	.91	23

[1] The coefficient of variation of the average predicted values, $\hat{Y}$'s, is estimated by SE $(\hat{Y})/\bar{Y}$.

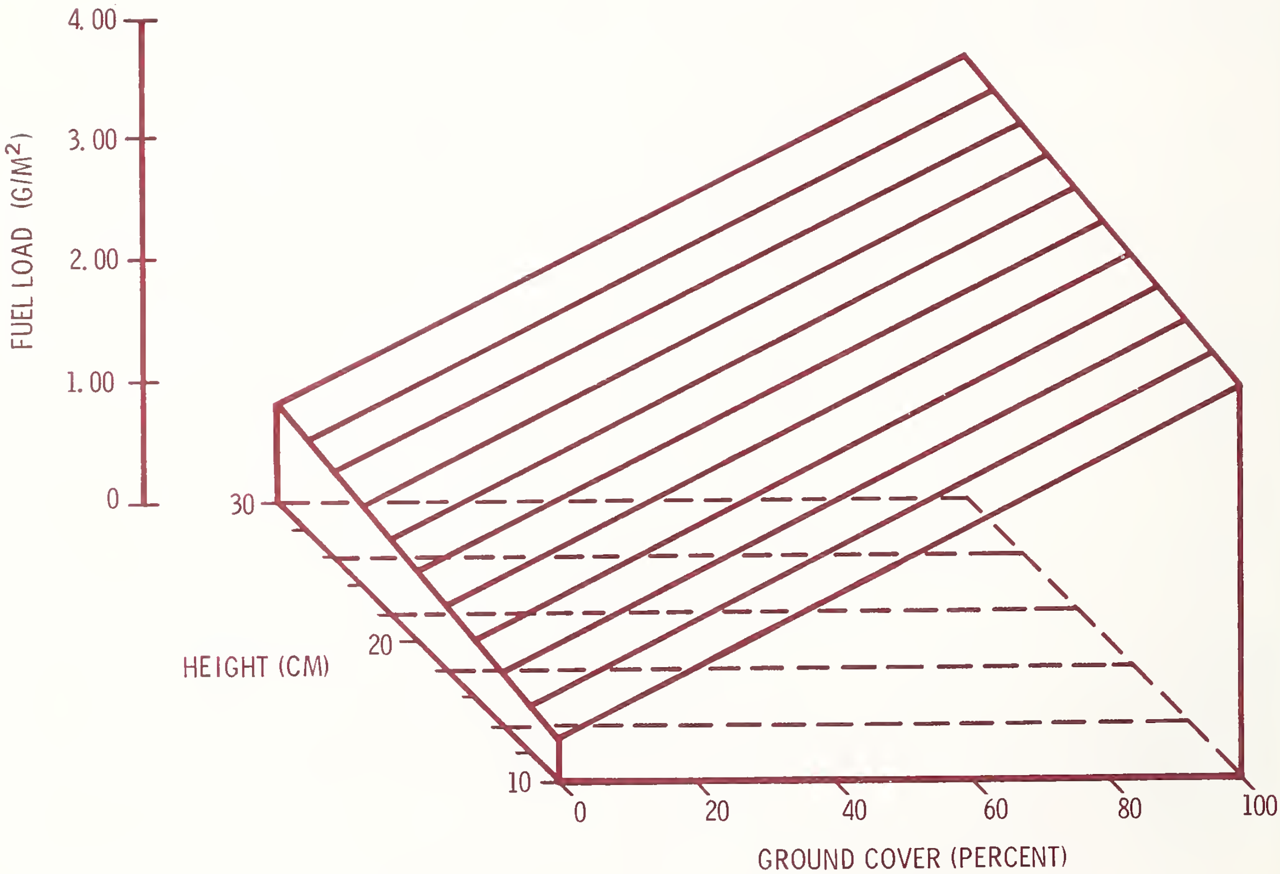

Figure 1.--Loading of grass as a function of coverage and height.

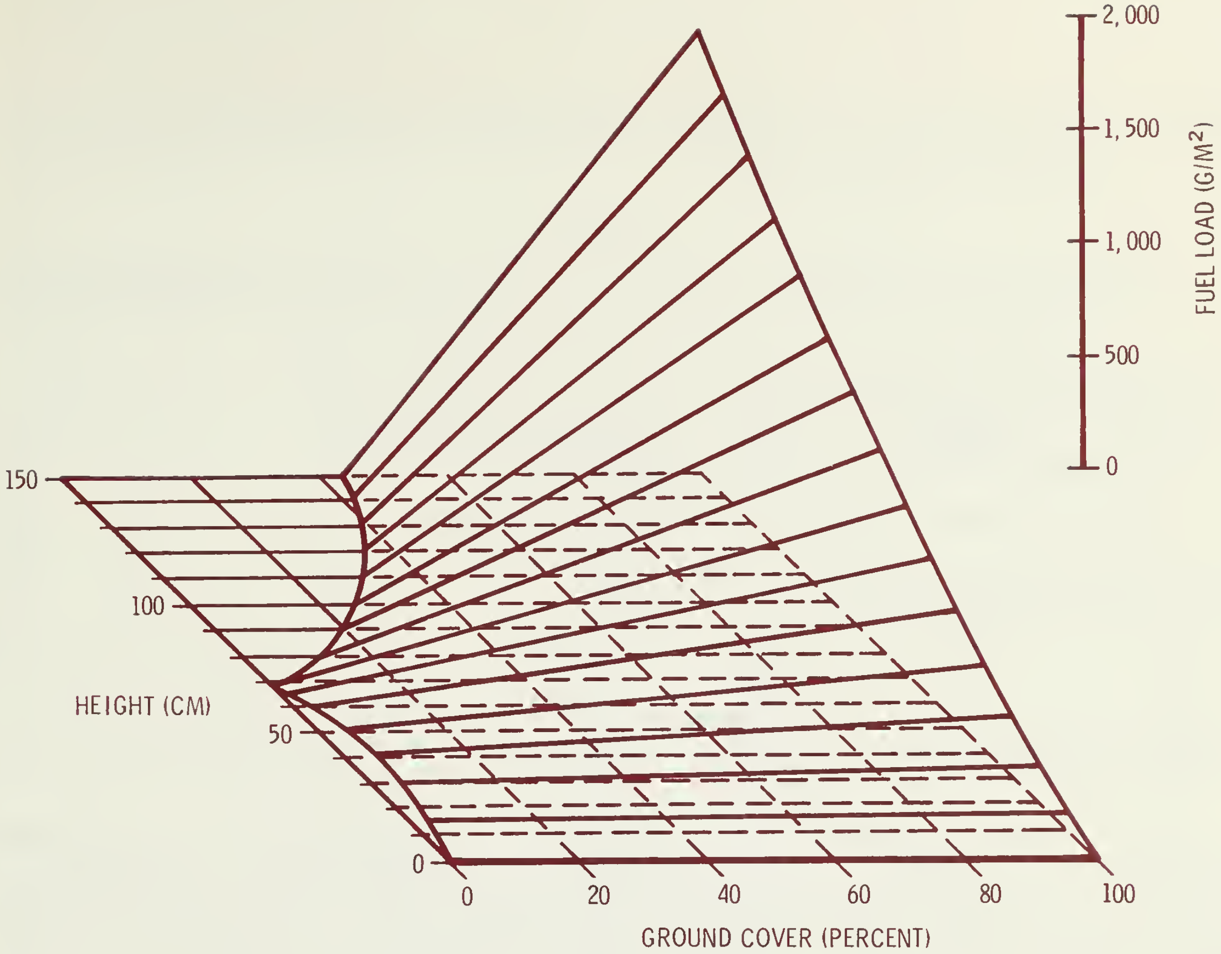

Figure 2.--Loading of broad- and narrow-leaved forbs combined as a function of coverage and height.

The use of separate equations for broad-leaved and narrow-leaved forbs did not produce significantly different predictions. This indicates that a combined forb equation could be used for estimating loading of all forbs. Our combined forb equation had a higher coefficient of variation than equations for either of the forb groups alone, which one might expect from combining data. This equation yields negative values for some combinations of ground cover (below 40 percent) and heights greater than 50 cm (fig. 2). More study is needed to determine whether a combined forb model can be developed that is adequately accurate for prediction over a range of ground covers and heights that might be encountered in the field. Our data are listed in the appendix in the event others wish to expand this study.

To help evaluate accuracy, measured loadings from another study[2] were compared with predicted loadings using some of the equations in table 2. Because the forbs were dominantly broadleaf type, predictions were made using the broadleaf as well as combined forb equations (table 3). In most cases, the broadleaf equation yielded smaller deviations than the combined forb equation. Average deviations expressed as the difference between predicted values and observed values divided by observed values ranged from a

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[2]Aldrich, David F. and Robert W. Mutch. 1972. Ecological interpretations of the White Cap Drainage: a basis for wilderness fire management, 109 p. USDA For. Serv., Intermt. For. and Range Exp. Stn. Prog. Rep. (Rev. Draft), North. For. Fire Lab., Missoula, Mont.

Table 3.--*Average deviations for loadings of grass and forbs from several habitat types in the Selway-Bitterroot Wilderness, expressed as predicted minus observed values divided by observed values*

Habitat type	Species group	No. of plots	Average deviations Actual	Average deviations Absolute
Abies lasiocarpa/Menziesia ferruginea	Broad-leaved forb	25	-0.81	0.83
	Combined forb	25	-.19	.53
Abies lasiocarpa/Clintonia uniflora	Broad-leaved forb		-.43	.56
	Combined forb	19	1.06	1.47
Abies grandis/Clintonia uniflora	Broad-leaved forb		-.22	.93
	Combined forb	91	1.11	1.50
Pseudotsuga menziesii/Xerophyllum tenax	Grass	13	2.28	2.35
Abies lasiocarpa/Xerophyllum tenax	Grass	116	-.15	.91

-0.15 to 2.28. In part, the large deviations were probably due to using the wrong equation for prediction. We were unsure of the species actually present because a list of species sampled was unavailable.

In developing equations that use ocular estimates of ground cover as an independent variable, the consistency of different observers comes into question. We found that consistency of different observers estimating ground cover on the same plots was rather good. In the test of consistency, ground cover ranged from 12 to 32 percent and averaged 22 percent. For the four pairs of observers, differences in ground cover estimates between observers ranged from 1.5 to 8.7 percent and averaged 5.8 percent.

This study shows that as different plant sizes and shapes are added to the data base for developing predictive equations, poorer accuracy can be expected. For appraising grass and forb fuels on specific sites, the mixed species equation from this study would provide questionable accuracy. To obtain adequate site-specific information, a technique involving some clipping and weighing seems necessary. However, for appraising fuels in broad vegetative groups, relationships between loading and ground cover and height can provide reasonable estimates.

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APPENDIX

Table 4.--*Raw data from plots of 1,800 cm² and predicted (P) minus observed (O) values expressed as a fraction of predicted values*

Stand ID	Dominant species[1]	Height	Cover	Observed loading	(P - O)/P
		SMALL WOODY PLANTS			
		Cm	*Percent*	*G/plot*	
1	24,1	10	30	32.6	- 0.28
1	24	10	10	12.1	.32
1	24,1	10	88	101.6	.25
1	24,1	10	53	48.0	.10
1	24,1	15	12	16.3	.08
1	24	10	95	191.6	- .21
1	24,1	10	55	65.1	- .14
1	24,3	10	17	16.5	.11
3	24,1,5	10	65	83.7	- .10
3	24,1	10	15	8.7	.52
3	24,1	10	65	75.4	.01
3	24,1	10	15	24.1	- .33
3	24,1,7	10	50	46.9	.04
3	24,1	10	55	52.4	.08
3	24	10	38	55.8	- .70
3	24,1	10	53	62.2	- .16
3	24,3	10	17	17.4	.07
3	24,3	10	65	69.9	.08
3	24,3	10	38	44.0	- .34
3	24,3	10	18	14.4	.24
3	24,1	10	50	49.8	- .02
3	24,1	10	70	85.4	.02
3	24,3	10	62	65.7	.06
3	24	10	38	40.6	- .24
3	24,1	10	11	9.5	.46
3	24,1,20	10	53	48.7	.09
3	24,1	10	63	45.0	.38
3	24,3	10	22	22.5	- .10
3	24,1,7	10	83	112.8	.07
3	24,1	10	22	27.6	- .35
3	24,1	10	32	26.3	.03
3	24	10	90	151.7	- .07

[1]See table 1 for numbered listing of species.

Table 4.--(con.)

Stand ID	Dominant species	Height	Cover	Observed loading	(P - O)/P
			BROAD-LEAVED FORBS		
		Cm	*Percent*	*G/plot*	
1	5	15	90	15.1	0.23
1	5	10	35	4.9	.50
1	5	10	10	1.6	.82
1	5	10	15	3.1	.66
1	5,1	10	30	5.4	.44
1	5,1	10	85	11.8	- .06
1	5,1	10	10	3.6	.60
1	5	20	35	3.9	.82
1	5	20	60	6.0	.76
3	5,1,10	10	85	19.8	- .79
3	5,10,25	10	70	17.0	- .59
3	5,1,25	10	95	19.0	- .67
11	5	5	10	1.5	.39
11	5	10	10	1.9	.79
13	5,1,8,24	14	52	15.6	.01
13	9,1,24	22	17	6.0	.72
13	7,1,8,25	9	61	15.0	- .68
22	5,6,9,25	15	58	11.4	.35
22	5,9	15	51	3.5	.80
22	5,9,11	15	60	5.7	.68
22	5	35	63	8.4	.81
31	5,12,11	20	68	7.1	.72
31	5,3	20	72	20.2	.22
32	14,11,25	13	23	2.8	.79
32	5,9,11,25	45	78	9.2	.86
32	11,9,25	12	28	4.2	.65
32	11,9,25	20	43	5.7	.75
32	5,9,22,11	25	81	8.7	.75
33	5,8	45	26	8.2	.77

Table 4.--(con.)

Stand ID	Dominant species	Height	Cover	Observed loading	$\frac{P - O}{P}$
			GRASSES		
		Cm	*Percent*	*G/plot*	
1	3	20	27	35.6	- 0.51
1	3	20	56	81.2	- 1.12
1	3	20	55	53.8	- .42
1	3	20	13	7.8	.53
1	3	20	9	7.6	.47
1	3	20	14	10.8	.36
1	3	20	51	85.2	- 1.38
1	3	30	60	93.1	- 1.08
3	1,2	10	90	71.2	- .39
3	1,2	10	95	68.7	- .28
3	1,2,5,7	10	80	49.7	- .07
3	4,5,8,10	10	95	44.8	.17
3	1,5	10	85	30.3	.38
11	1,5,6,25	12	18	2.6	.83
11	1	10	10	1.3	.88
11	1,5,7	10	45	7.9	.72
11	1,5	15	35	9.6	.62
11	1,5	10	17	5.0	.65
11	1,5,6,8	22	38	6.9	.77
11	1,5,8,25	21	58	17.9	.55
12	3	7	14	8.3	.27
12	3	17	49	33.5	.00
12	3,22	9	38	12.5	.49
13	1,5,8	27	39	13.9	.58
13	1,5,6	12	42	18.6	.33
13	3,22	20	46	38.2	- .15
13	1,5,6	17	29	4.3	.82
13	1,5,6,7	22	40	9.9	.68
21	3,9,25	35	58	52.5	- .14
21	3,12	7	12	40.7	- 2.96
21	3,11	20	41	48.8	- .59
21	3,11,12	25	88	13.3	.77
22	3	13	68	60.4	- .46
23	1,9,22	50	85	48.9	.26
23	4,11	10	75	23.6	.46
23	4,10,6,9	10	30	20.4	.02
32	3	10	75	75.6	- .73
32	3	20	23	58.8	- 1.73
34	4,9	10	70	17.2	.58
34	4,5,10	10	70	46.0	- .12
35	1,5,10	10	85	40.0	.18

Table 4.--(con.)

Stand ID	Dominant species	Height	Cover	Observed loading	(P - 0)/P
		NARROW-LEAVED FORBS			
		Cm	*Percent*	*G/plot*	
1	19	75	90	150.7	- 0.18
1	18,19	50	32	39.8	.03
1	18,19	60	82	96.9	- .06
1	18,19	45	50	75.5	- .53
1	18	40	9	13.1	.51
1	18	30	30	26.1	.14
1	18,19	55	55	131.1	- 1.15
1	18,20	65	29	65.1	- .73
1	19	50	52	58.2	- .06
1	18	60	48	99.3	- .72
1	18	40	16	13.0	.57
1	18,7	30	7	7.5	.69
1	18,19	35	52	53.6	- .31
1	18	20	30	17.1	.20
1	18	30	48	30.5	.12
1	18	65	11	29.1	- .75
1	17,7	73	75	88.2	.14
1	17,5	55	83	89.1	- .06
1	17,7	73	18	31.3	- .72
1	17	45	62	65.8	- .17
1	17,5,10	41	82	111.8	- .84
1	17	60	18	11.7	.58
1	19,17,21	71	80	84.8	.20
1	17,5	55	94	129.0	- .38
1	17	100	62	14.7	.85
1	17	45	27	21.7	.41
1	17	100	34	49.0	- 1.09
1	20,8	10	25	25.6	- 1.71
1	17,21	27	65	150.6	- 3.31
1	21	45	37	41.2	.02
1	17,5	77	25	30.7	- .20
1	17	100	45	102.8	- .91
1	17	55	15	14.0	.49
1	17,1	72	30	41.9	- .15
1	17,1	55	49	50.8	.09
1	17,5,8	15	95	96.6	- 3.87
20	23	125	99	221.5	.18
20	23	115	99	274.4	- .13
20	23	100	99	195.4	.04
20	23	150	99	387.7	- .13
20	23,9	135	99	495.1	- .66
20	23	150	99	416.3	- .22

Table 4.--(con.)

Stand ID	Dominant species	Height	Cover	Observed loading	(P - O)/P
		NARROW-LEAVED FORBS (con.)			
		Cm	*Percent*	*G/plot*	
20	23	150	99	205.2	.40
20	23	135	99	306.0	- .03
20	23	110	99	90.4	.61
20	23	105	99	254.6	- .18
23	22	75	45	35.2	.39
23	22	10	70	20.9	- .96
23	19,8,25	14	38	21.8	- .45
23	23	25	41	19.4	.31
23	22,6	35	68	31.9	.31
23	22,6,11	21	17	5.4	.74
23	17,1	130	88	118.6	.49

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